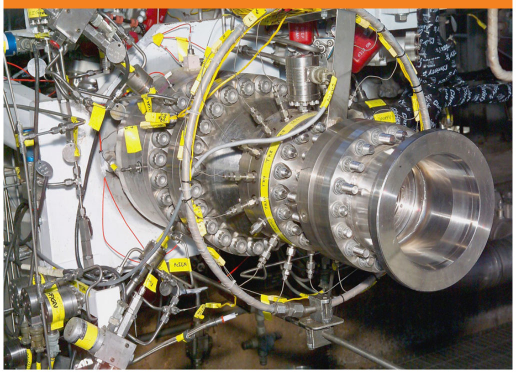
National Aeronautics and Space Administration

Structural Materials/
Thermal Materials

Novel Nanolaminates

NASA Marshall Space Flight Center



Materials constructed of extremely thin (on the order of nanometers) alternating layers of different materials often exhibit novel qualities that are far different from the bulk properties of the contributing materials. While the behavior of composite materials is usually governed by the "rule of mixtures," in which their properties are an average of those of the contributing materials, the properties of nanolaminates are determined by the layer thicknesses and detailed structures of the interfaces between layers. This attribute makes it possible for researchers to tailor materials with specific property values, such as strength, oxidation resistance, and reduced hydrogen embrittlement.

The aerospace industry has shown great interest in the potential of nickel/aluminum oxide (Ni/Al_2O_3) metal-matrix composites (MMCs) as an advanced propulsion material, such as those used in rocket engine preburners (above). The focus of this task is the engineering of a Ni/Al_2O_3 nanolaminate that is expected to have better strength, creep and fatigue resistance, oxygen compatibility, and corrosion resistance than traditional MMCs.

Task Description

To demonstrate the distinctive properties of a Ni/Al_2O_3 nanolaminate, this Advanced Materials for Exploration (AME) task will:

(1) Modify an existing Chemical Vapor Deposition (CVD) facility at the University of Alabama in Huntsville to include computer control of alternating vapor sources

(2) Use CVD to manufacture Ni/Al_2O_3 nanolaminates of several thicknesses, alternating nanolayers of Ni and Al_2O_3

(3) Characterize the material structures and determine intra-lamellae spacing with X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and optical microscopy techniques

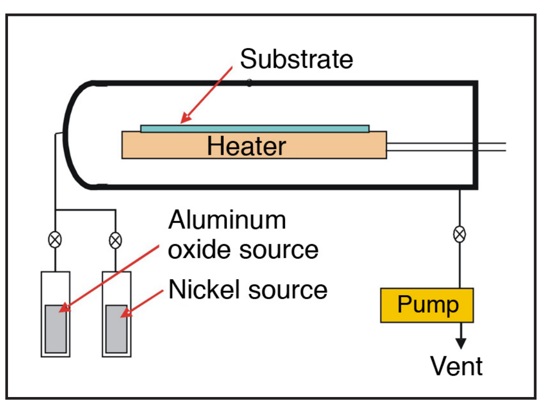
(4) Manufacture thicker bilayered materials to test for mechanical strength at elevated temperatures [up to 800 °C (1472 °F)]

(5) Compare resulting nanomaterials properties to Ni-based MMCs and Ni-based superalloys.

This 10-month task began in December 2005 and will culminate in September 2006.

Anticipated Results

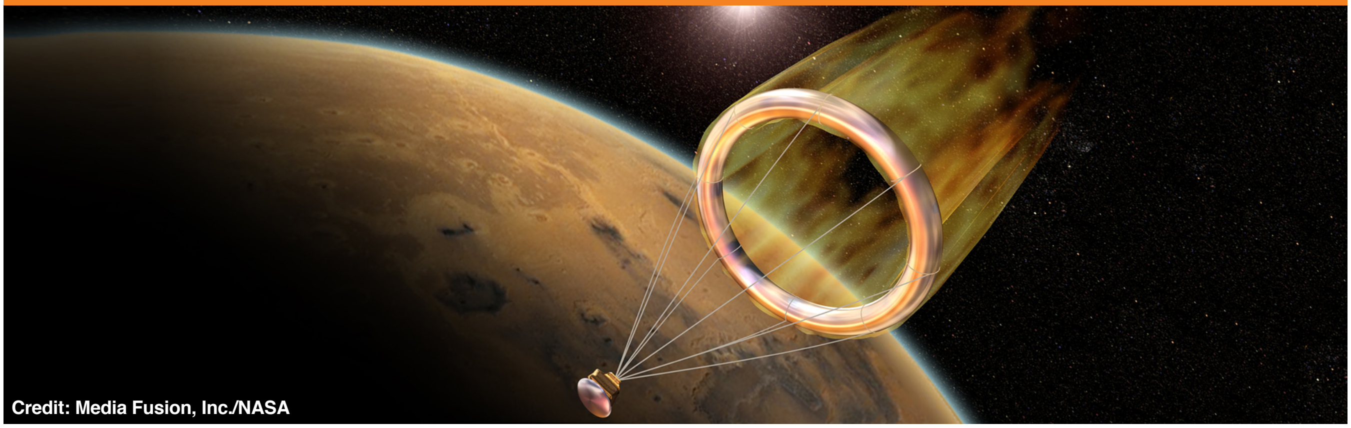
The manufacturing process is a critical factor in nano-engineering. Investigators selected CVD because it is less expensive than physical vapor disposition techniques, often yields better microstructures, and can be used to manufacture complex shapes. The research team has developed a CVD technique and processing equipment



Chemical Vapor Diffusion process

advanced materials for exploration

NOVEL NANOLAMINATES



Nanolaminate materials are expected to improve the performance of ballute materials by increasing their strength and ability to function at the high temperatures associated with aerocapture in planetary atmospheres.

to deposit films of Al_2O_3 and Ni and will use this technique to engineer Ni/Al_2O_3 laminate structures comprised of up to thousands of alternating layers. The resulting material is expected to exhibit significant resistance to hydrogen embrittlement, be 30% lighter than Ni, and possess heretofore unequaled strength from ambient temperatures to 1000 °C (1832 °F).

First, investigators will deposit single or just a few layers to establish the optimal CVD parameters. Using facilities in the Materials and Processes Laboratory and the National Center for Advanced Manufacturing at Marshall Space Flight Center, the team will characterize these materials by SEM (surface characteristics and lamellae spacing), XRD (orientation and size of the grains and intra-lamellae space), optical microscopy (microstructure quality), and profilometry (total layer thickness). When they have determined the best deposition conditions, researchers will fabricate thicker samples [0.5 x 4 mm and >1 mm thick (0.02 x 0.16 in. and >0.04 in.)] with hundreds of nanolayers in several bilayer thicknesses (10, 20, 50, and 100 nm). These samples will be characterized mechanically and metallographically using tensile pull and hardness indentation tests to evaluate strength at elevated temperatures [>800 °C (1472 °F)]. The thermo-mechanical properties of the Ni/Al_2O_3 nanolaminates then will be compared with those of Ni alloys and Ni/Al_2O_3 MMCs.

Potential Future Activities

Successful demonstration of the advanced properties of Ni/Al_2O_3 nanolaminates will be of interest to developers of improved rocket engine components, such as injector faceplates and bodies and preburners. Another potential application is in ballute structures. A thin nanolaminate coating no thicker than a few micrometers could enhance the polyimide thin films currently used for ballute structures, improving strength and operations at temperatures above 500 °C (932 °F). The nanolaminate may also have a desirable thermal anisotropy. Heat conduction through the layers will be far less than heat conduction along the layers. CVD fabrication of rolls of a nanolaminate-coated polyimide foil and of free-standing foil structures [0.05 to 0.2 mm thick (0.002 to 0.008 in.)] is possible. The potential for metal alloys with protective alumina coatings to show increased resistance to hydrogen embrittlement is another future potential investigation.

Capability Readiness Level (CRL)

At the completion of this task, the CRL of Ni/Al_2O_3 nanolaminates will have increased from 1 to 3.

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FS-2006-06-65-MSFC